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SUMMARY

A full-size pilot-controlled simulation of the Gemini-Agena docking has been completed by using a six-degree-of-freedom dynamic simulator. The simulation was composed of three studies designed to investigate: (1) the pilot's ability to aline the Gemini and Agena vehicles by using only visual information (no instruments) and displacement control, (2) terminal docking accuracies by using the direct control mode in attitude as well as translation under both day and night lighting conditions, and (3) visual aids which could increase the pilot's precision and confidence in the docking maneuver.

Results indicate that both a lack of available visual cues and the pilot's control were responsible for the terminal errors. With adequate visual information pilots were able to complete a successful docking consistently under both day and night lighting conditions.

INTRODUCTION

Since the results of the Mercury program have demonstrated man's control and decision-making capabilities in the space environment, many groups have studied ways to utilize further the pilot's capabilities. One area in which considerable work has been done (refs. 1 to 6) involves pilot-controlled docking, in which the pilot maneuvers his spacecraft to couple, or dock, with another vehicle. One of the primary missions of the Gemini program is to develop the necessary techniques for and to accomplish a pilot-controlled docking in space.

Although earlier studies of simulated docking (ref. 4) have shown that a pilot can dock satisfactorily, the Gemini pilot will have problems of limited field of view, visual parallax, and cross coupling between attitude and translation control forces. In cooperation with the Manned Spacecraft Center, these problems were investigated in a full-size six-degree-of-freedom dynamic simulation of the Gemini-Agena docking utilizing Langley's rendezvous docking simulator (ref. 7).

This report includes the results of the docking simulation in the areas related to the pilot's visual capabilities and requirements. The areas investigated included: (1) the pilot's ability to aline the Gemini and Agena vehicles by using only visual information obtained from target observation, (2) terminal docking accuracies with pilot control during night or day missions by using visual information only, and (3) visual aids which could increase the pilot's precision and confidence.

SYMBOLS

t	flight time, sec
W	weight of fuel, lb
X,Y,Z	coordinate axes
x,y,z	longitudinal, lateral, and vertical displacement, respectively, ft
θ	pitch angle, deg
ϕ	roll angle, deg
ψ	yaw angle, deg

Subscripts:

c	with respect to the Gemini center of mass
n	with respect to the Gemini nose
t	translation fuel
a	attitude fuel
f	total fuel

A dot over a quantity indicates the first derivative with respect to time.

DESCRIPTION OF APPARATUS

Gemini-Agena Design and Characteristics

The Gemini spacecraft is a two-man vehicle designed for orbits of extended duration and for pilot-controlled rendezvous and docking in space. The Gemini has two control systems: the reentry control system (RCS), which is activated shortly before retrograde and used during retrofire and reentry into the atmosphere, and the orbit attitude and maneuver system (OAMS), which is used for all other phases of spacecraft control including rendezvous and docking with the Agena target vehicle. Control of the spacecraft attitude through the OAMS (fig. 1) is accomplished by selection by the pilot of four functional modes of control, one automatic (horizon scan) and three manual (rate command, direct, and pulse). In the rate command mode, movement of the attitude hand controller produces spacecraft angular rate about each axis proportional to the displacement of the controller. Automatic stabilization of the angular rates is provided from sensing of rates by the rate gyros. With the hand controller centered, or at a neutral position, the spacecraft rate about each axis is damped to within a small rate deadband. In the direct control mode the jets are fired directly by actuation of the attitude hand controller. Angular acceleration is the maximum provided by the thrusters for the period of hand-controller deflection from neutral. This control mode is more difficult since the pilot must control spacecraft rates as well as attitude. In the pulse command mode, jet-firing commands are manually initiated by hand-controller displacement. A fixed "on" pulse results, and angular acceleration is the maximum provided by the thrusters for the duration of each pulse and independent of the period of handle deflection. Only the direct mode of spacecraft attitude control was considered in this study. Translation control is similar to the direct attitude control mode in that deflection of the three-axis maneuver hand controller fires the translation thrusters directly, with no velocity feedback signals provided.

In the direct control mode the Gemini pilot must concern himself with considerable cross coupling of angular rates and control inputs about the spacecraft axes. In addition to the normal inertial coupling of angular rates which occurs when more than one of the rates are finite, significant coupling is caused by the relation of the control jets to the center of mass of the spacecraft. The eight OAMS attitude thrusters are located aft from the center of mass near the end of the adapter section to provide a sufficient moment arm and are fired in pairs. The roll jets produce a couple, but firing of the pitch and yaw jets, in addition to providing the desired torques, results in spacecraft translations. Also, with the control configuration studied, firing of the vertical and lateral translation jets which were not directed through the mass center produced significant attitude torques in pitch and yaw. The disturbance torque in pitch and yaw introduced by the vertical and lateral translation thrusters was roughly one-third of the available control power of the attitude thrusters.

A 14-inch indexing rod extends from the top center of the Gemini rendezvous and radar module about 11 inches from the tip of the nose. If the terminal attitude and translation errors are within the Agena tolerances, the indexing rod passes into a V-shaped slot in the Agena docking cone and alines the docking cone with the Gemini nose for latching. Design docking tolerances of the Agena cone are $\pm 10^{\circ}$ in attitude, ± 1 foot in radial displacement, ± 0.5 foot per second in lateral and vertical velocity, and 1.5 feet per second in longitudinal velocity.

The flight control system of the Agena target vehicle is designed to measure and stabilize the attitude of the vehicle within a small deadband relative to the local vertical during the docking maneuver. Drift in attitude within the deadband was disregarded in this simulation because the period was long and was believed to be a second-order factor in pilot control.

Simulation Facility and Operation

The Gemini-Agena docking simulator involved a full-size model of the cabin and nose sections of the Gemini spacecraft (fig. 2), associated drive systems, a general-purpose analog computer, and a full-size model of the Agena target. The facility's design, operation, and capabilities are described in detail in reference 7. The Gemini model was mounted in a hydraulically driven gimbal system which provided three degrees of freedom in attitude (pitch, yaw, and roll). The entire model and gimbal system were, in turn, mounted in a horseshoe-shaped frame which was suspended by eight cables from an overhead bridge-crane system. The electrically driven bridge-crane provided three degrees of translational freedom (longitudinal, lateral, and vertical). Thus, the model was driven in six degrees of dynamic freedom to approach and dock with the stabilized Agena target.

The pilot, seated on the left side of the Gemini model, actuated a three-axis side-arm attitude controller located between the seats and a three-axis pencil-type translation controller located near the left arm of his seat to command the model to move in the desired direction for alinement and closure with the target. (See fig. 3.) Moving either the translation or attitude controller closed a microswitch which transmitted a voltage to the analog computer. The analog computer solved the equations of motion and then transmitted the rate and position command to the appropriate drive system.

The target was a full-size model of the Agena target vehicle suspended from the ceiling. It was painted flat white and did not have latching facilities on the docking cone.

Computer Program

A general-purpose analog computer closed the control loop between the pilot and the simulator. The pilot's control inputs were transformed from the Gemini body-axis system to an inertially fixed axis system alined with the axes of the drive system and then were integrated to give velocity and position. These velocity and position commands were fed to the simulator drive systems which moved the Gemini model as though it were the actual vehicle in space.

PROCEDURE AND DATA ANALYSIS

Simulation Procedure

Docking flights were made using initial offsets from 40 to 120 feet longitudinally, up to 5 feet vertically and laterally, and from 5° to 10° displacement about all three axes from a wings-level/straight-ahead attitude. No initial rates were used for two reasons. First, if high initial rates were used, the pilot's first task would be to bring the rates near zero before initiating the docking. Second, the cross coupling induced small attitude and translation rates when the pilot corrected initial displacements.

Nine National Aeronautics and Space Administration (NASA) test pilots took part in the simulated flights. Their background and experience were invaluable in evaluating the control task, simulator response, and piloting techniques and were particularly invaluable in the visual-aids study which depended largely on pilot comments for evaluation.

Data Reduction and Analysis

Three types of data were obtained in the simulations: (1) data recorded as time histories on continuous charts on 16 data channels, (2) digital readouts of all outputs recorded on tape at the end of each run, and (3) the pilot's comments. The continuous charts showed time histories of control inputs, velocities, and attitudes throughout each flight.

Since final docking accuracies could be measured and digitally recorded at the end of each flight, most of the quantitative data are expressed in terms of final displacement errors, rates, flight time, and fuel use. Displacement errors were measured between the center of mass of the spacecraft and the center line of the target at the termination of a docking flight; the termination point defined as the point at which the longitudinal distance x between vehicles became zero.

Two digital computations were performed on the digital readout data from the analog computer. The velocity and position error of the nose of the spacecraft was calculated from the center-of-mass data, and then the terminal velocities, position errors, fuel use, and flight time were averaged for each set of related flights.

The third type of data obtained - pilot comments - naturally does not lend itself to quantitative analysis. As far as qualitative data are concerned, comments by the test pilots have been very instructive. Pilots' comments were transcribed during and following the data flights. Because of the importance of the pilots' opinions, which in many cases were as important as the quantitative data, pilot comments have been included wherever possible in this report.

Cases Studied

For the docking maneuver simulated, the cockpit was not instrumented; therefore, the pilot obtained all information (range, range rate, attitude, and so forth) from just the visual cues afforded by the Agena target. Three phases of the docking simulation, designed to investigate various visual aspects of the Gemini docking, were: (1) the pilot's ability to aline the Gemini and Agena vehicles by using only visual information (no instruments) and displacement control, (2) terminal docking accuracies under both day and night lighting conditions, and (3) visual aids which could increase the pilot's precision and confidence in the docking maneuver. In the second and third phases, the direct control mode in attitude, as well as in translation, was used.

Four trained pilots took part in the first phase, conducted to determine how much of the pilot's difficulty in properly alining the two vehicles under daylight conditions was due to the inability to position the Gemini to the desired location because of the control system and how much was due to the pilot's inability to determine visually, under daylight conditions, the correct alinement. To isolate this problem, the model was displaced laterally, vertically, and in attitude at various ranges from 5 to 110 feet from the target, and the computer operator (rather than the pilot) positioned the Gemini model, as directed by the pilot seated in the model. In this way, any alinement error was a result of the pilot's visual capability. After the model and target were alined to the pilot's satisfaction, translation and attitude errors were recorded, and the pilot was asked to estimate the range between the two vehicles. The range-estimation test was made primarily to compare the results with those of a previous range-estimation study reported in reference 8.

The object of the second phase of the simulation was to determine the difference in difficulty of docking under daytime and nighttime lighting conditions. Day and night docking differed by two factors. First, only the target cone was illuminated; thus, the pilot had to use the cone itself, rather than the body of the target, for the orientation cues, and the lack of aspect made the problem, in effect, one of docking with a two-dimensional rather than a three-dimensional target. Second, the nose of the Gemini was not lit, so the pilot saw the indexing bar only when it was silhouetted against the illuminated target cone; consequently, recognition of the attitude of his own ship was made more difficult.

Three NASA pilots who were well trained in the docking operation took part in this phase. Each made 10 docking flights during the day and 10 flights at night, and the same set of initial conditions was used during both the day and night flights. To eliminate as many extraneous cues as possible, a 40- by 100-foot black curtain was suspended from the hangar ceiling behind the target. The curtain hid the wall and rafters behind the target and obscured the windows at the docking end of the hangar. Since all the windows of the hangar in which the simulator was located could not be covered, some ambient light did filter in, even on a dark night. With all the lights off, it was possible for the pilot to become sufficiently dark adapted within a period from 3 to 5 minutes so that he could see the rafters above the simulator, and the rafters could be used to obtain extraneous velocity cues. The dark adaptation was averted in two ways: a bright light was placed in the cockpit to destroy the pilot's adaptation between flights, and the pilot was required to start from about a 45-foot range, rather than the 120-foot range used in other studies, so that by the time the pilot could become sufficiently adapted to use extraneous cues, he was at such close range that the target required his full attention.

For the third phase, several visual aids were tried on the model and target to see if such aids could increase docking precision and pilot confidence, particularly at night. Since the time for this study was limited, it was impossible to define the optimum scheme. There was time only to investigate several simple techniques and to point out those which were found to offer the most promise.

Pilots were told that neither time nor fuel was critical and that they were to use the closure technique which they preferred to effect a successful final docking. A flight was deemed successful if all terminal conditions were within tolerances. A simulated flight which ended out of tolerance did not necessarily indicate that the Gemini docking was unsuccessful. The low contact velocities used (0.2 to 0.5 foot per second) should cause no damage, so the Gemini pilot could back off and try to dock again, even after contact, if necessary.

RESULTS AND DISCUSSION

Visual Alinement Accuracies

Figures 4(a) and 4(b) show the average errors in displacement and attitude, respectively, at various ranges for four pilots. Since the model was moved by the computer operator to the exact position the pilot desired, the vehicle alinement errors can be considered to represent the daytime docking errors caused by the lack of visual cues. The docking errors from the flights in which the pilot had complete control are composed not only of these visual errors but also of errors caused by pilot control.

Table I compares the visual alinement errors at a 5-foot range with the terminal displacement errors from 30 daytime docking flights that were controlled by the pilots. There are no more visual cues available at docking contact than there are at a 5-foot range, so the vehicle alinement error which occurs when there is no piloting control can be considered as representing the docking errors caused by the visual environment. The difference between the terminal errors and alinement errors can be interpreted as the errors which the pilot either could not or, because of allowable tolerances, did not correct.

Table I indicates that most of the translation errors were caused by the lack of visual cues rather than by control. The error caused by control was more noticeable in the case of the pitch and yaw attitudes (approximately 2° with no control) where the control was responsible for about half of the terminal displacement error. Roll error caused by the visual cues was much smaller (approximately 1°) and roll error caused by pilot control was considerably higher (approximately 4.5°) than the respective pitch and yaw errors. This result is logical because the angle between the Agena docking slot and the Gemini indexing bar provides a very good roll reference and because the OAMS roll acceleration is about $1\frac{1}{2}$ times the pitch and yaw acceleration, making it more difficult to make precise roll corrections.

The results of the range estimations are shown in figure 5. As the figure is read from left to right, it can be seen that the model was initially displaced 110 feet from the target and was brought monotonically into a 5-foot range; the model was then brought back out to 100 feet, with estimates given at intermediate points. The figure shows that the pilots tended to underestimate the range at all distances (compare with ref. 8) and that the estimates were slightly more accurate as the model backed away from the target. The underestimation provides an inherent safety factor.

Comparison of Day and Night Docking

The average terminal conditions of both the day and the night flights are presented in table II and several interesting results are shown.

First, as would be expected, pilots were more cautious in approaching the target at night. The closure rate $\dot{x}$ was lower, with a corresponding increase in flight time t.

Second, the terminal rates (except $\dot{x}$) in both the day and night flights were low, and the difference is not really meaningful because a rate of a fraction of an inch per second or degree per second is below the limit of the pilot's control precision with the cross coupling and control mode used.

The third result of interest is the average terminal displacement. At first the results appear to be ambiguous. Table II shows that the pilots were more accurate, on the average, in positioning the nose of the model at night but were more accurate in alining the attitude and center of mass of the vehicle during the day flights. This apparent discrepancy is actually a logical result of the pilot's performance of the docking maneuver under two dissimilar visual environments. Pilots preferred to control the docking by initially alining the axes of the model and target and then maintaining the alinement during closure to contact. During day flights this procedure was possible because the pilot could see both the nose of the spacecraft and the entire body of the Agena target which he could use to determine the center line of each vehicle and thus maneuver to aline the two axes. At night, however, with only the docking cone illuminated it was difficult, if not impossible, for the pilot to determine precisely the vehicle's axes. Pilots realized this difficulty and apparently concentrated more on flying the indexing bar into the docking slot and paid less attention to axis alinement; as a result, the pilots positioned the indexing bar slightly more accurately at night (about 1 inch), with a small sacrifice in vehicle alinement.

It should be noted that alinement would be much less a problem if it were not for the parallax caused by the Gemini configuration. If the pilot's line of sight were in the same plane as the indexing bar, he would not need to see the nose of the spacecraft or the body of the target but would only have to line up his eyes, the indexing bar, and the docking slot in the same way the front and back sights of a gun are lined up on a target. Unfortunately, the pilot's line of sight was displaced laterally about 1.5 feet from the plane of the indexing bar (the XZ-plane), causing a visual angle of 9.4° between "straight ahead" (parallel to the spacecraft center line) and the bar. The parallax is apparent in figure 6 which shows the view from the cockpit with the vehicles alined 15 feet apart.

Probably the most important result of the day-night study is the percentage of flights in tolerance. As noted earlier, a flight judged "out of tolerance" in the simulation does not necessarily indicate that the orbital docking would be dangerous or damaging but only that the Gemini pilot would have to back off and try to dock again. The substantially smaller percentage of flights in tolerance (table II) at night does indicate the need for some type of aid which would increase the visual cues at night and thereby increase the pilot's confidence.

Some pilot comments on the day-night phase were:

The depth perception at night is practically negligible at distances greater than 5 feet away. At about 5 feet some depth cues become available, and within 2 feet of the target the depth perception is completely restored.

Judgment of rates of displacement and rates of angular motion at night is a little more difficult but is within a person's capability. At close ranges, this judgment poses no particular problem. It is much easier to stay on an approach path in the daytime than at nighttime because of the additional cues that are available during the day. At long ranges it is almost impossible to determine the extended longitudinal axis of the target at night, but at close ranges the target cone provides sufficient cues to determine the axis.

Relative motion between the vehicles can be controlled at night because lower rates are used; because of these lower rates a flight requires more time, and more fuel is used.

Visual Aids

The next logical step was to look for a technique whereby the pilot could either eliminate or disregard the parallax and whereby the pilot's visual cues would be increased. The obvious answer would be to place the indexing bar and docking slot directly in front of the pilot's eyes. This modification would require an integral change in both the Gemini and the Agena vehicles. The alternative, and the course taken in this investigation, was to try simple visual aids which could be added to the existing configuration without a major modification and which could reduce the inaccuracies, particularly those in the nighttime docking.

Two types of visual aids were indicated. The first type of aid would be a light to illuminate the nose of the Gemini so the pilot could determine the attitude of the spacecraft. A floodlight mounted at the top of the model (fig. 7) to illuminate the nose was found to be satisfactory. The second type of aid would provide a reference for alining the axes of the spacecraft and target. Several aids were tried (fig. 8), but the most satisfactory aid consisted of two illuminated lucite rods vertically mounted, one at the front and one at the back of the target, along the pilot's line of sight. Figure 9 shows the lucite bars mounted on the target. The rods provided a good yaw and lateral translation reference.

The average terminal conditions for the flights in which the visual aids were used are compared with the terminal conditions for the day-night comparison flights in table III. When the lucite rods were used, all terminal displacement errors were less than those at night without the aids and were even less than some of the end conditions of the day flights. The final nose positions, in particular, were more accurate with the visual aid than either day or night flights without it. Final translational rates and flight times were comparable. Final attitude rates with the aid were higher but were well under control.

Again, the most important result of the visual-aid flights is probably the percentage of flights in tolerance. Table III shows that the pilots did much better at night with the aids than without them. Although the percentage of successful flights with the aids was lower than in daytime flights, the percentage would possibly be higher if the pilots had made more flights and had become more familiar with the aids.

Another way of analyzing the data could possibly show the effect of using the visual aid more clearly. Three pilots (A, B, and C) participated in day and night flights, and the day-flight results were compared with those of the night flights. The visual-aid flights in which the illuminated rods were used were made by two pilots (A and D). Since pilots B and C did not take part in the visual-aid flights and pilot D did not take part in the comparison flights, the average terminal conditions (table IV) could reflect different pilots' abilities, as well as the flight conditions and visual environment. Therefore, only the terminal conditions for pilot A, who made both the visual-aid and comparison flights, were averaged and tabulated in table IV. (It should be noted that all test pilots who participated were well trained, gave useful comments, and were able to control the simulator with all cross coupling to the desired rates and positions.) Pilot A, either because of training or natural ability, had more consistent and more accurate terminal conditions in all cases flown than any of the other test pilots. Table IV shows that the average lateral velocities and fuel uses were comparable. Pilot A took slightly longer to make the flights with the illuminated rods and had higher terminal angular rates. Time, of course, was not particularly important, and the angular rates were well under control. Final displacement errors, the most critical end conditions, were as good or better with the visual aid than either day or night flights without it. Using the visual aids, pilots were able to approach the precision and confidence in the night dockings that they had during the day. This increase in accuracy does not mean that a visual aid is necessary for day flights. Pilots agreed that, after training, they could consistently dock within tolerance during the day. It does mean, however, that if an aid were used for night dockings it would not degrade and could possibly increase the terminal accuracy for daylight dockings.

Pilots made the following comments concerning the visual aids:

As far as the technique of night flight is concerned, some type of light on the Agena target and some type of light which would illuminate the nose of the Gemini to indicate the spacecraft axes are needed.

The light on the Gemini appears to be minimal.

The light on the Gemini makes it possible to determine the spacecraft axes. Without an aid on the target, it is difficult to tell the relative attitude of the two vehicles at night. The visual aid on the target provides a reference for the target axis.

CONCLUSIONS

The results of the simulation of the Gemini-Agena docking maneuver wherein the pilot used only visual information and direct acceleration command mode of spacecraft control indicate the following conclusions:

1. Pilots were confident of the docking maneuver during the day and, after training, could consistently dock within the Agena tolerances by using the direct (acceleration-command) control mode.

2. Most of the translation errors existing at the termination of pilot-controlled docking flights appeared to be caused by the visual cues available. Pilots were capable of visually alining the Gemini and Agena within about 1° roll and 2° pitch and yaw at docking. The particular control mode used could be expected to increase these errors.

3. The factors responsible for most of the terminal inaccuracies were the parallax caused by the pilot's having to observe the indexing bar on the center of the nose of the spacecraft from his seat which was laterally displaced from the center line of the spacecraft and by the pilot's inability to separate attitude and translation errors.

4. It appears highly desirable to illuminate the Gemini nose, particularly the indexing bar. The light source could, conceivably, be as simple as a flashlight beamed through the window by the copilot while the pilot controlled the Gemini to docking.

5. The best target aid tested in these studies consisted of two illuminated lucite rods, one mounted at the front and one at the back of the target along the pilot's line of sight. The rods were mounted vertically and provided a good yaw and lateral translation reference. The aid was not necessarily optimum and could have been improved by mounting a horizontal bar for pitch and vertical translation reference and by "color coding" the rods so it would be easier to tell them apart.

6. Using the visual aids, pilots were able to approach the precision and confidence in the night dockings that they had during the day.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., October 20, 1964.

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TABLE I.- COMPARISON OF VEHICLE ALINEMENT ERRORS

Parameter	Unit	Alinement error	
		With no control	With direct control mode
Lateral error	feet	0.34	0.49
Vertical error	feet	.27	.30
Pitch error	degrees	1.66	3.25
Yaw error	degrees	1.15	2.82
Roll error	degrees	.89	4.51

TABLE II.- AVERAGE TERMINAL CONDITIONS OF DAY-NIGHT COMPARISON FLIGHTS

	Day	Night
Displacement:		
y_n, ft	0.62	0.57
z_n, ft	0.62	0.52
y_c, ft	0.49	0.78
z_c, ft	0.30	0.48
ψ, deg	2.82	4.86
θ, deg	3.25	3.98
ϕ, deg	4.51	5.85
Rate:		
$\dot{x}$, ft/sec	0.50	0.39
$\dot{y}$, ft/sec	0.11	0.06
$\dot{z}$, ft/sec	0.11	0.14
$\dot{\psi}$, deg/sec	0.60	0.41
$\dot{\theta}$, deg/sec	0.60	0.90
$\dot{\phi}$, deg/sec	0.94	0.55
Fuel, lb:		
W_t	2.9	5.5
W_a	1.1	2.2
W_f	4.0	7.7
Time, t, sec	122	208
Flights in tolerance, percent	97	73

TABLE III.- AVERAGE TERMINAL CONDITIONS OF DAY AND NIGHT FLIGHTS AND NIGHT FLIGHTS WITH BAR AID

	Day	Night	Bar aid
Displacement:			
y_n	0.62	0.57	0.46
z_n	0.62	0.52	0.49
y_c	0.49	0.78	0.65
z_c	0.30	0.48	0.44
ψ	2.82	4.86	3.68
θ	3.25	3.98	3.02
ϕ	4.51	5.85	3.33
Rate:			
$\dot{x}$	0.50	0.39	0.65
$\dot{y}$	0.11	0.06	0.11
$\dot{z}$	0.11	0.14	0.12
$\dot{\psi}$	0.60	0.41	1.28
$\dot{\theta}$	0.60	0.90	1.25
$\dot{\phi}$	0.94	0.55	1.66
Total fuel, W_f	4.0	7.7	9.8
Time, t	122	208	166
Number of flights	30	30	11
Flights in tolerance, percent	97	73	85

TABLE IV.- AVERAGE TERMINAL CONDITIONS FOR PILOT A

	Day	Night	Rods
Displacement:			
y_n	0.80	0.79	0.35
z_n	0.60	0.63	0.67
y_c	0.55	0.56	0.18
z_c	0.24	0.37	0.24
ψ	1.85	1.97	1.29
θ	4.17	4.43	2.11
ϕ	6.62	7.20	4.34
Rate:			
$\dot{x}$	0.67	0.55	0.54
$\dot{y}$	0.05	0.05	0.08
$\dot{z}$	0.03	0.03	0.06
$\dot{\psi}$	0.46	0.31	1.04
$\dot{\theta}$	0.33	0.65	0.91
$\dot{\phi}$	0.38	0.45	0.56
Total fuel, W_f	2.17	3.68	3.0
Time, t	98	153	199
Number of flights	10	15	4
Flights in tolerance, percent	100	100	100

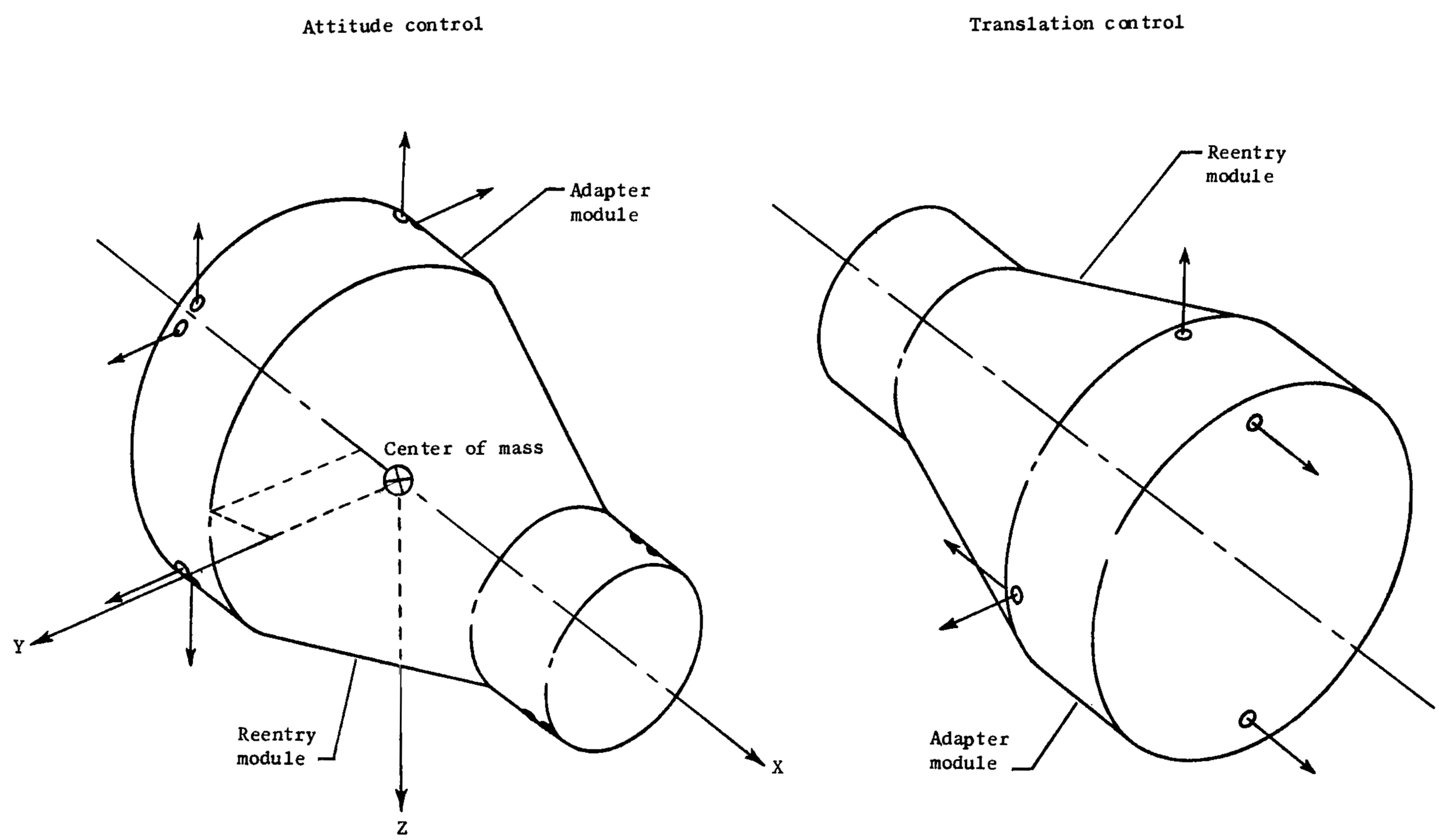


Figure 1.- Orbital attitude and maneuver system of the Gemini spacecraft.

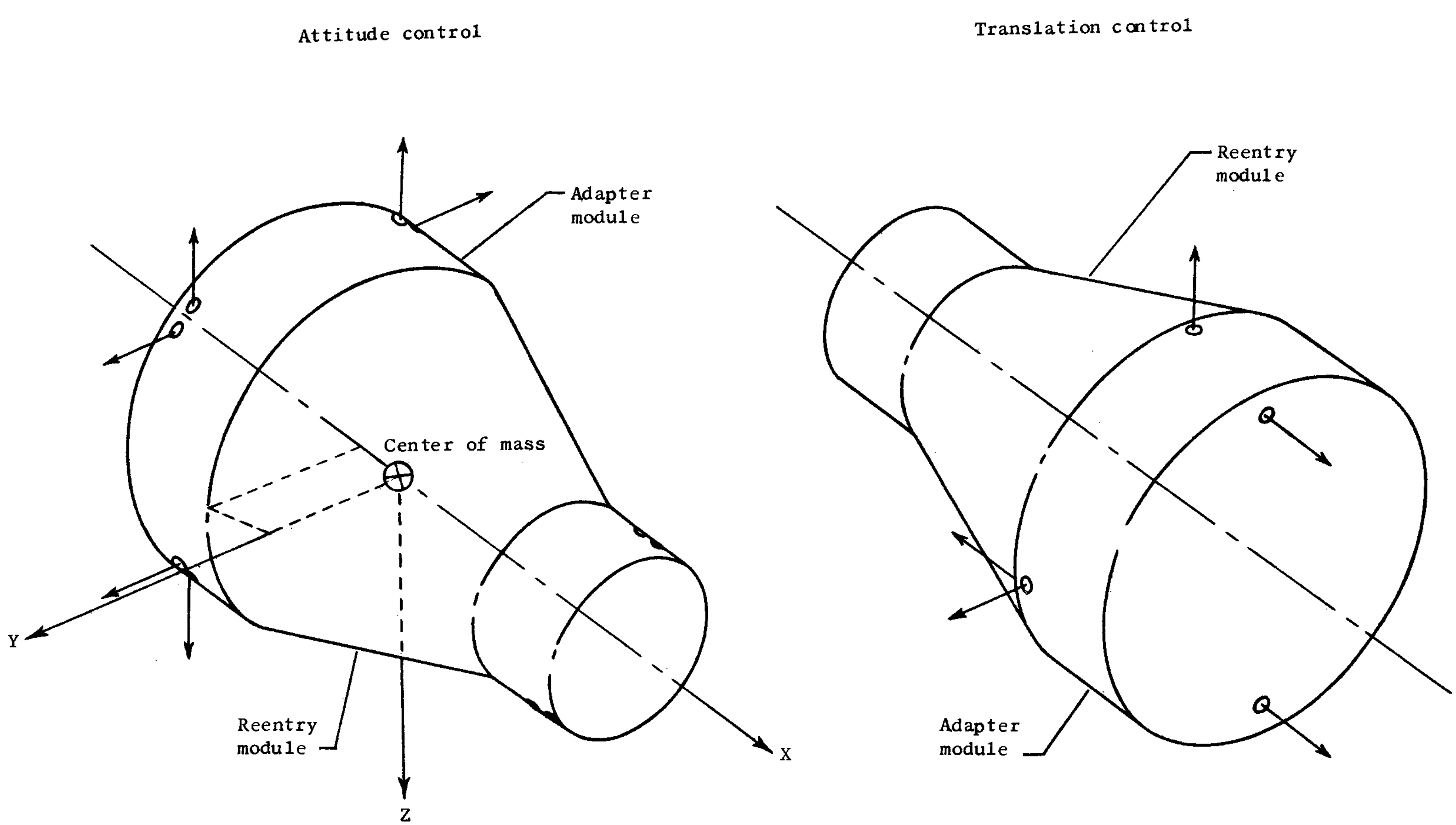


Figure 1.- Orbital attitude and maneuver system of the Gemini spacecraft.

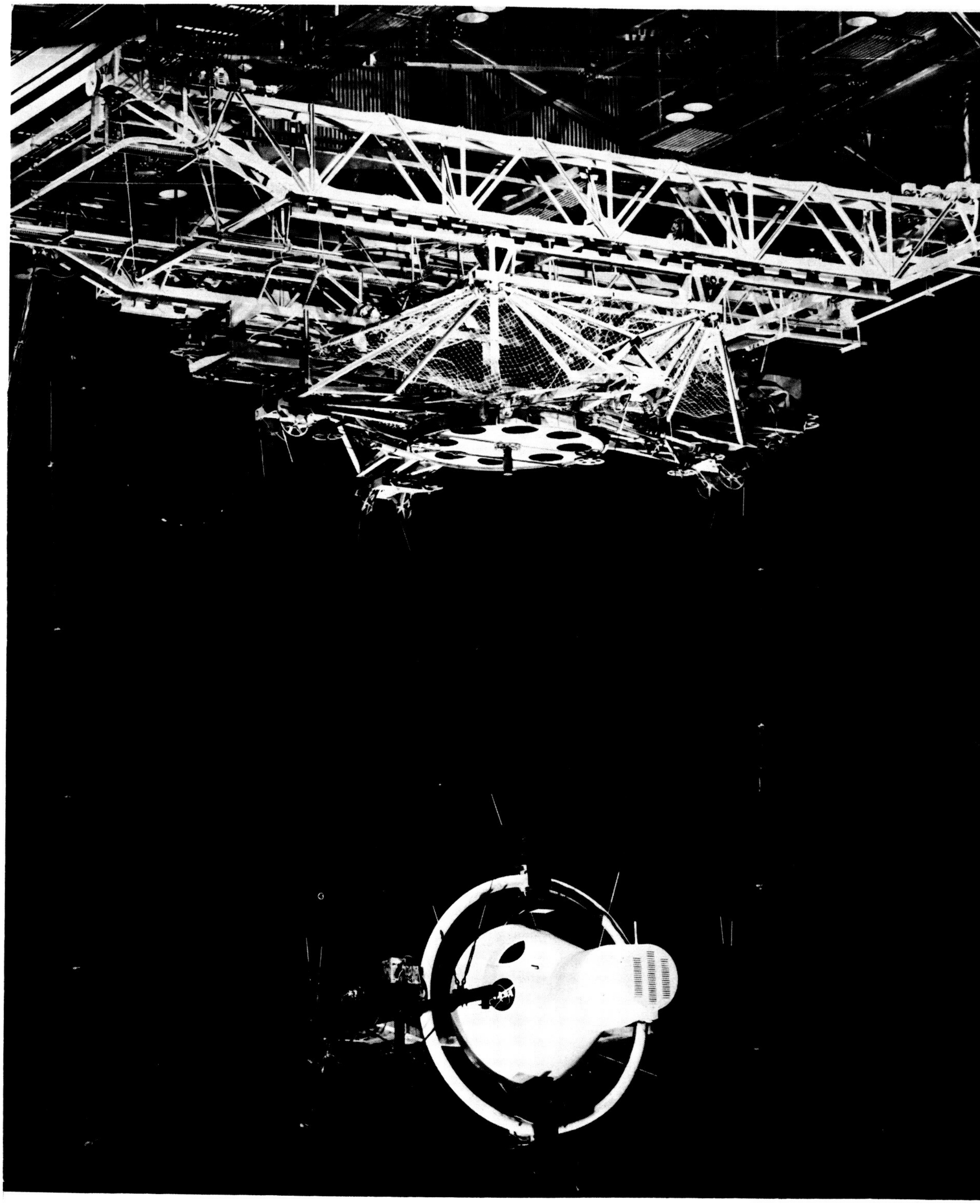
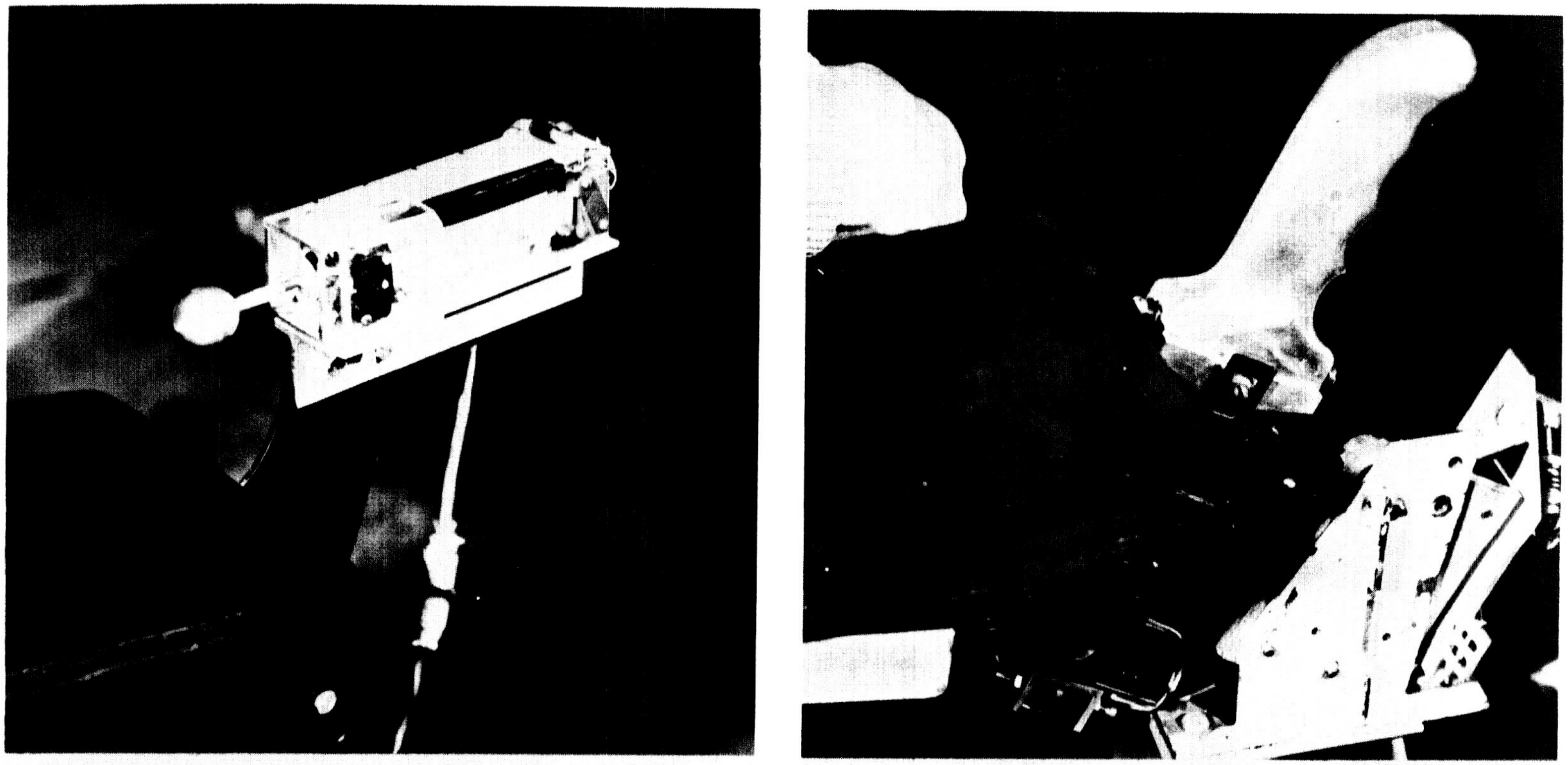


Figure 2.- Langley rendezvous docking simulator. L-64-4307

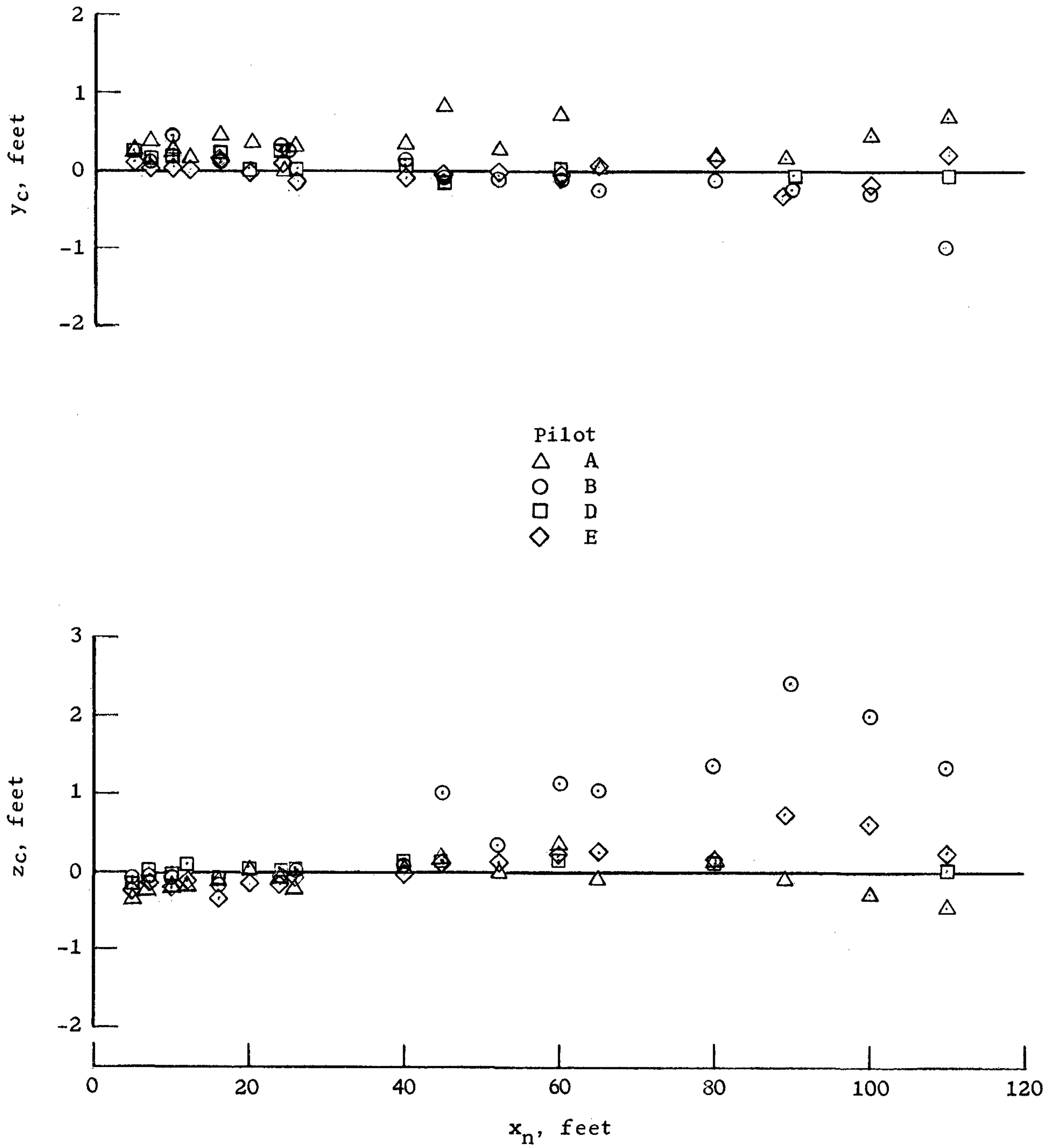


TRANSLATION CONTROLLER

ATTITUDE CONTROLLER

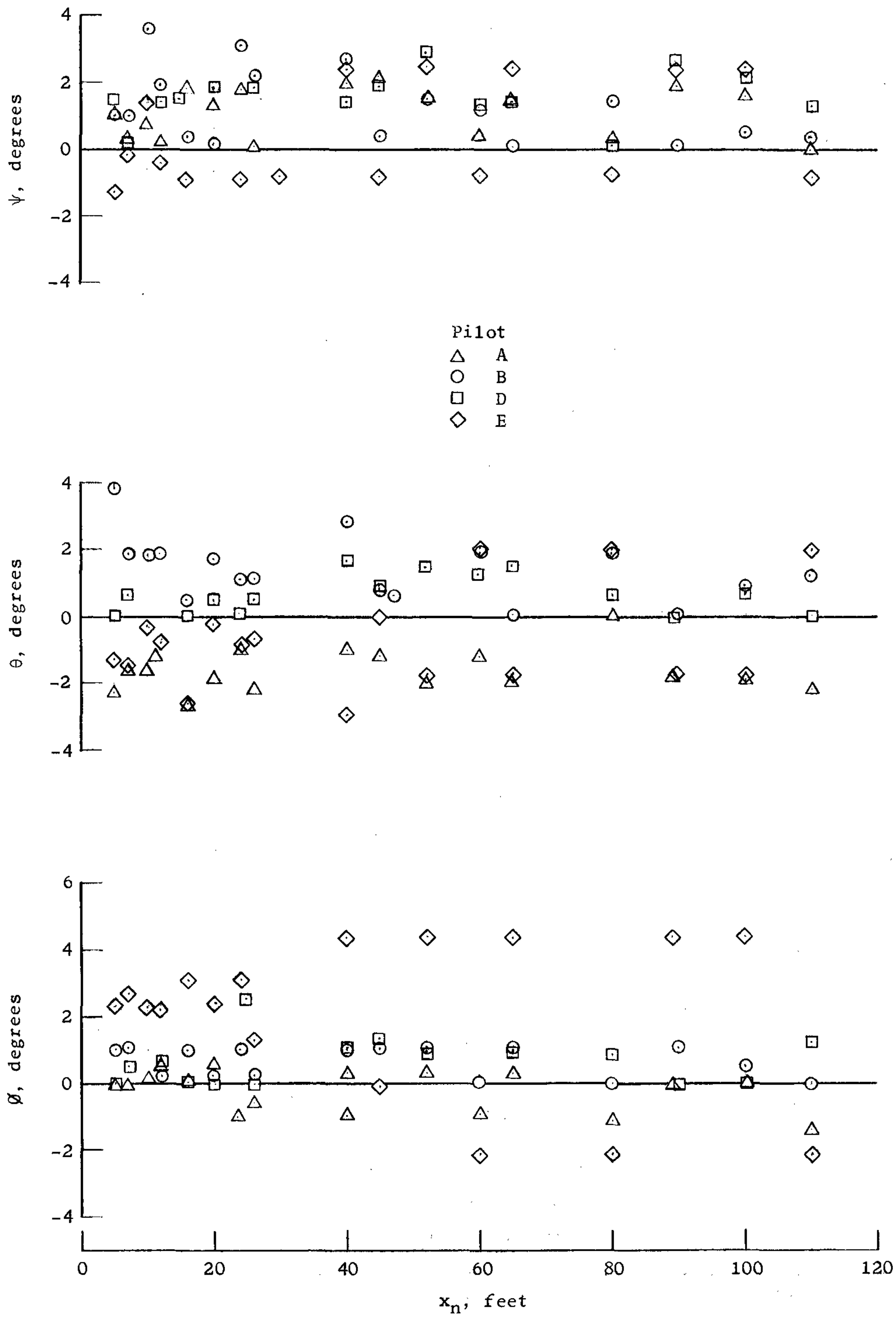
Figure 3.- Three-axis controllers.

L-2276-7



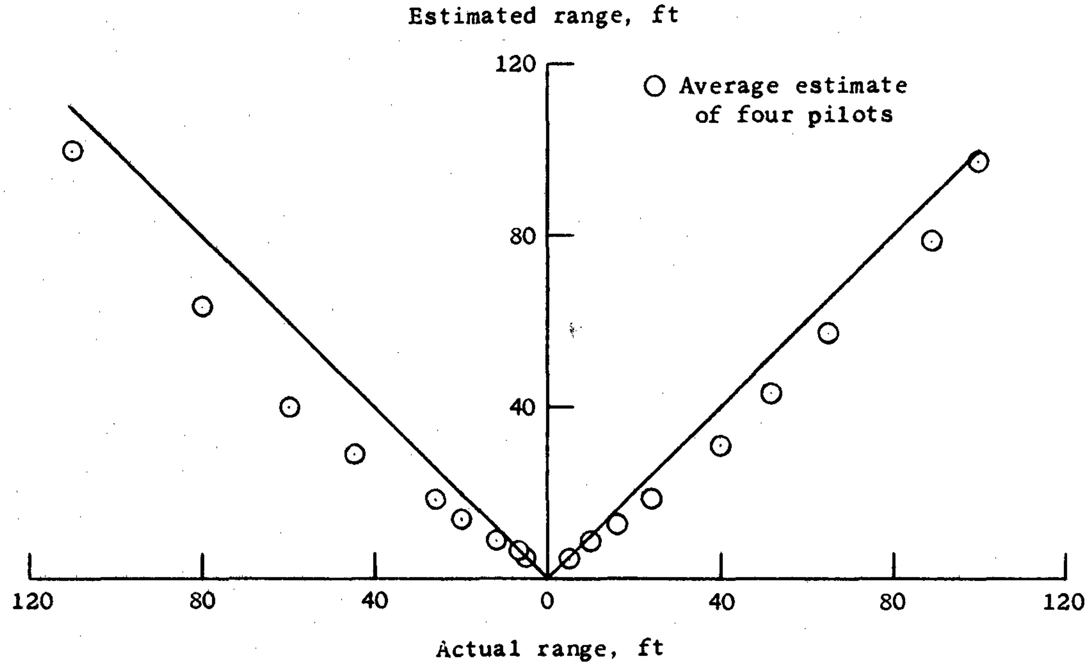
(a) Translation.

Figure 4.- Alinement accuracy as function of range.



(b) Attitude.

Figure 4.- Concluded.



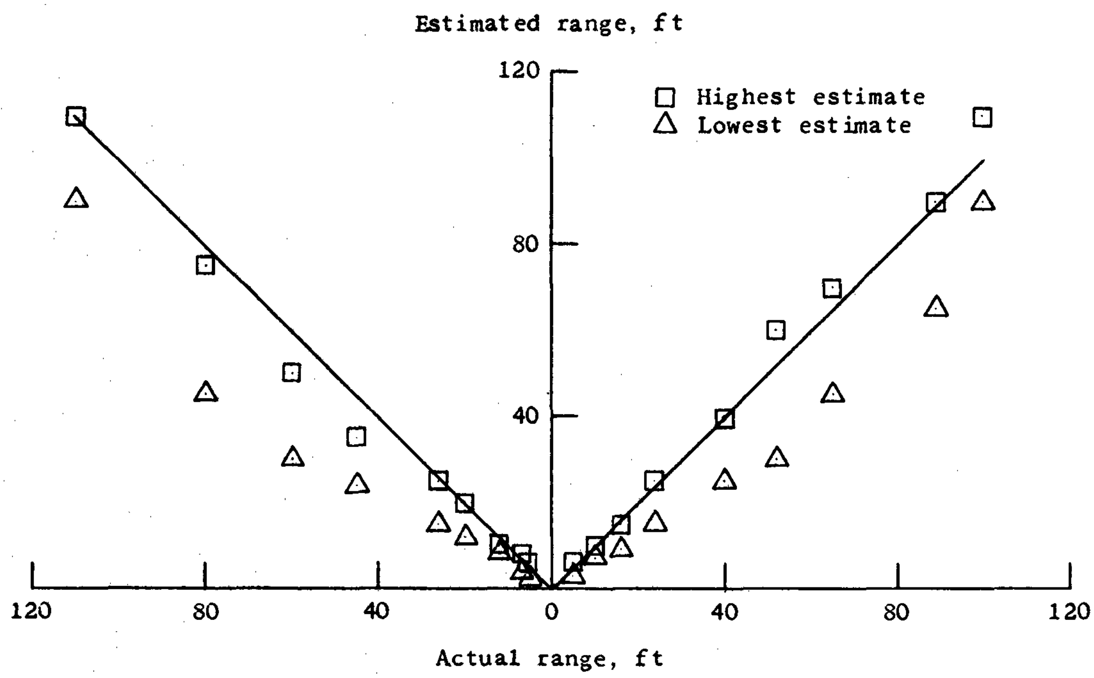


Figure 5.- Estimated range plotted against actual range.

Figure 6.- View of target from cockpit at 15-foot range, showing visual parallax. L-63-8873

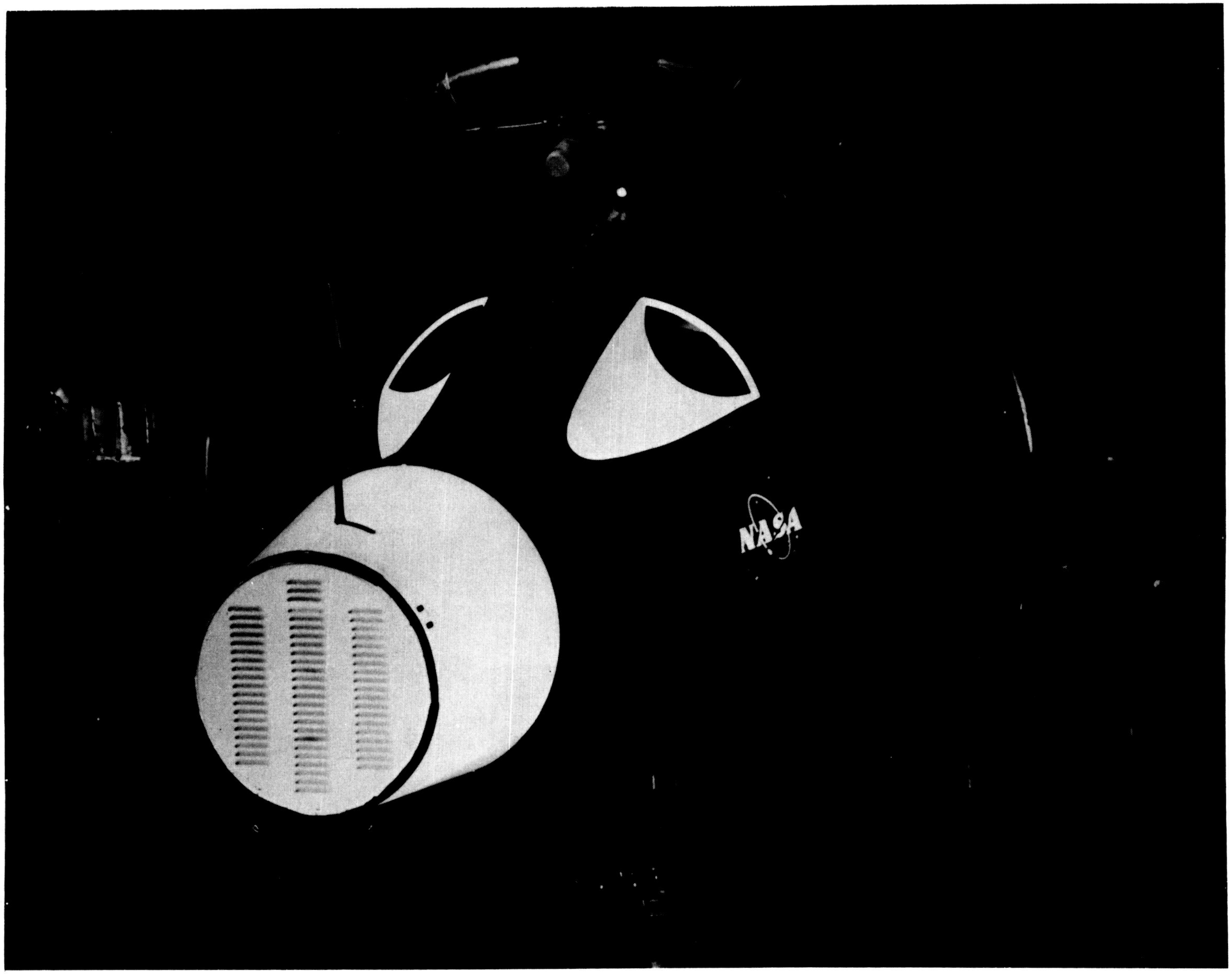


Figure 7.- Floodlight used to illuminate Gemini nose.

L-64-3565

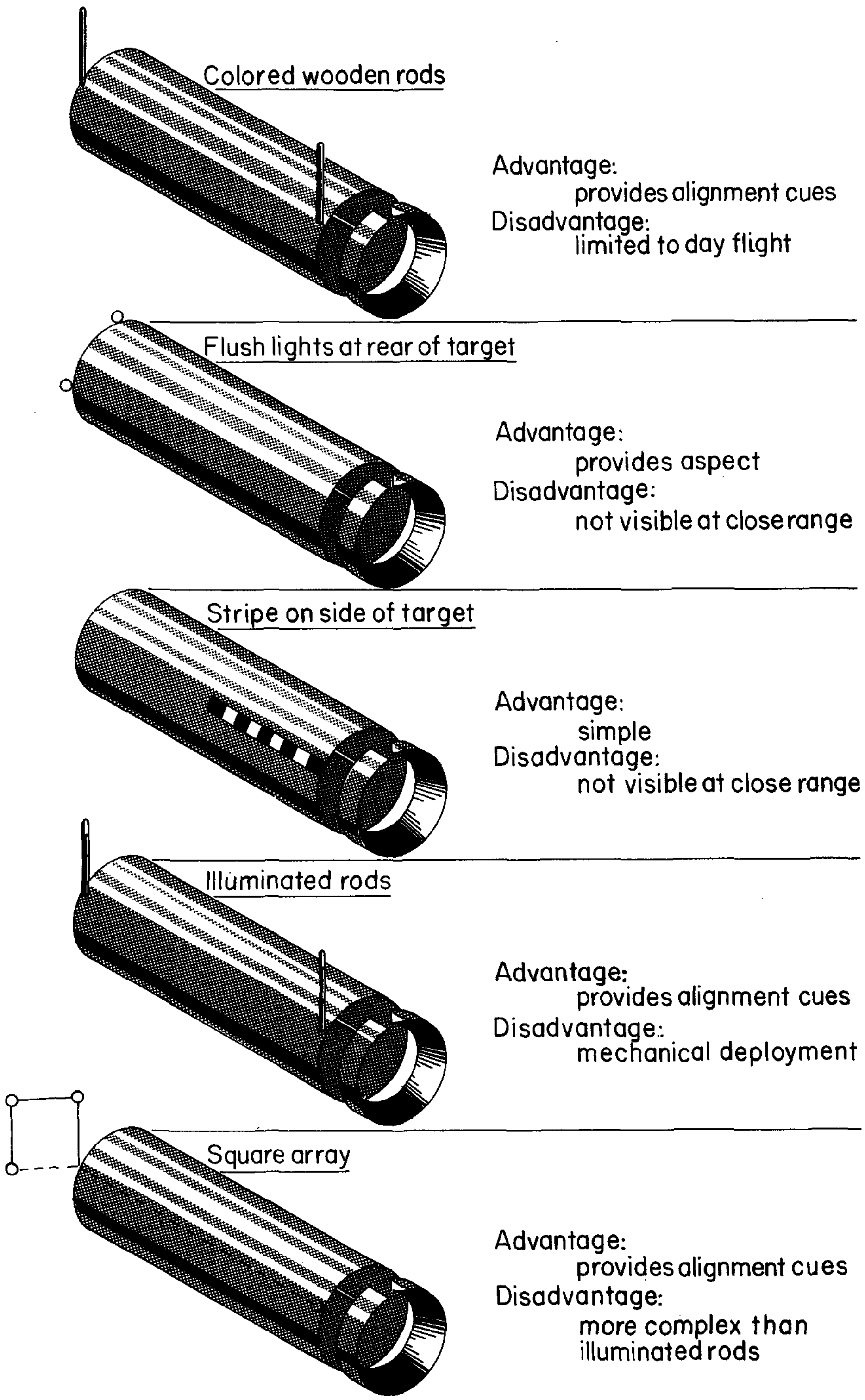
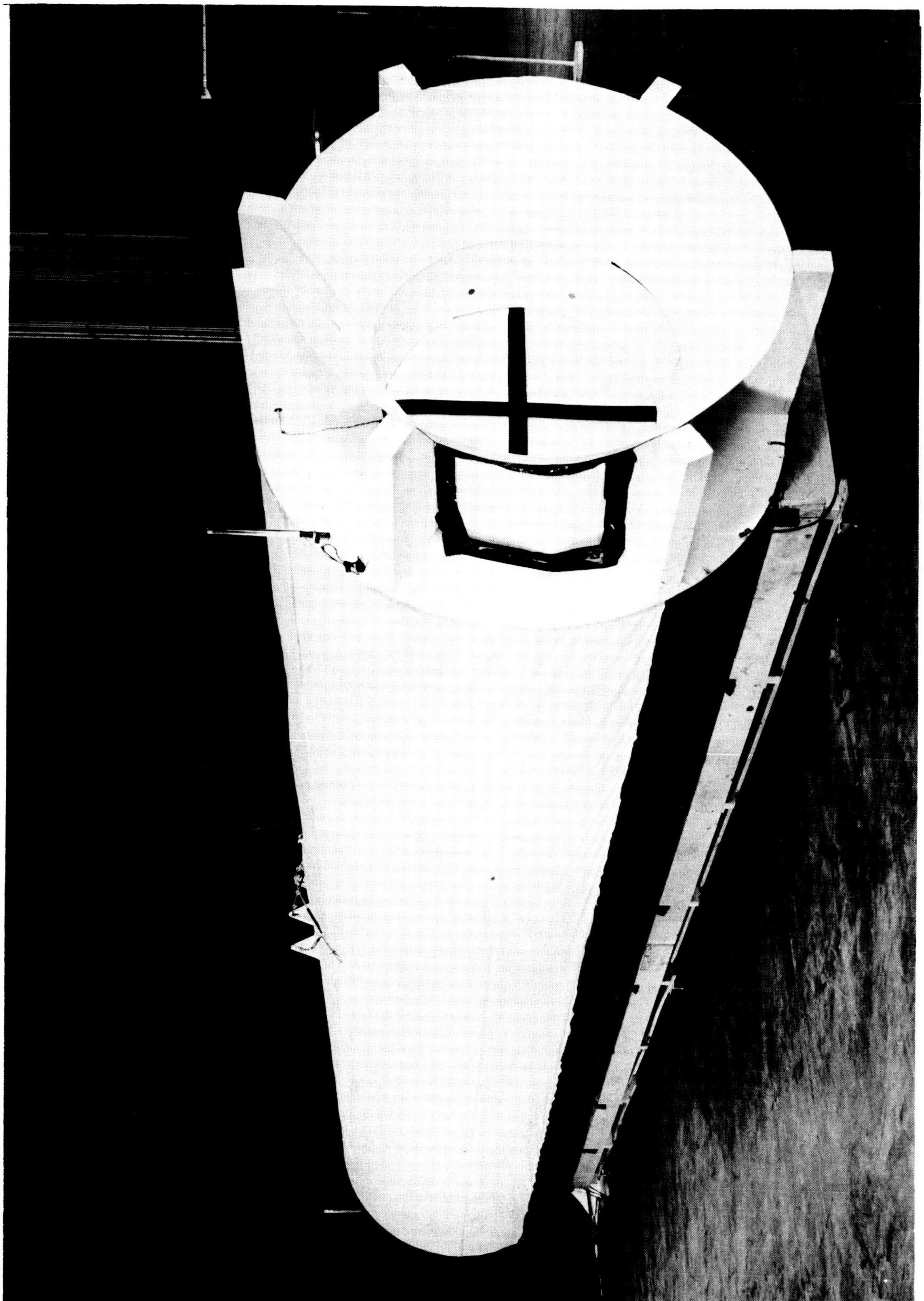


Figure 8.- Visual-aid techniques investigated.



L-64-708

Figure 9.- Lucite-rod aids on front and back of Agena target.

NASA-Langley, 1965 L-4144

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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